STRENGTHENING OF REINFORCED CONCRETE BEAMS WITH GLASS FIBER REINFORCED POLYMER SHEETS WITH DIFFERENT CONFIGURATIONS IN SHEAR AND FLEXURE

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ABSTRACT

Reinforced concrete is the supremely used building material in the world. Most structures made up of reinforced concrete as a main construction material but all of it are not able to fulfil their structural functions due to various reasons. It is not feasible to replace such deficient structure with new structure every time as it requires lot of investment of money, so strengthening of structure with different techniques become viable option for such deficient structures.

In this study, total 15 no. of beam were casted under three different categories i.e. full strength beam, beam weak in shear and beam weak in flexure. Beams were of M35 grade concrete mix. Beams were strengthened with Glass Fiber Reinforced Plastic sheet which was procured from Sika® India. Glass Fiber Reinforced Plastic sheet were applied in different configurations on those beams with using epoxy resin. Beams were tested under one point loading and load was noted for every 0.5 mm interval of deflection of beams. From that results, stiffness and energy absorption parameters were found out. Based on these results, different comparisons were made and effect of strengthening was found out.

Keywords*: *Flexure, GFRP sheet, Shear, Strengthening, Wrapping

I. INTRODUCTION

Reinforced Concrete (RC) is one of the common and widespread building material in the world. Many structures like bridges, buildings etc. uses reinforced concrete as their principal construction material. Due to various reasons, these structures faces reduction in their strength. So that there is a possibility that the structure should not take its designed load. So these structures or parts of it are not fulfilling their structural functions due to defects on the concrete caused by corrosion, poor construction practices, accidental damage, fire damage or deterioration caused by environmental action. Whereas some reinforced concrete structures need to be upgraded due to design and construction faults and in cases of load increment or damage induced to the structural members by the earthquake or any other action. Also, there is construction of many structure in paste designed by older codes are became unsafe with introduction to newer codes. So replacing these deficient structures

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requires huge investments and is not a viable option, hence strengthening of structure is only appropriate way for increasing the load capacity and prolonging their service life.

FRP composites are useful in increasing strength and ductility without increasing stiffness. So in recent times using externally bonded FRP composites plates concrete members can be easily and effectively strengthened. By wrapping FRP sheets, strengthening of concrete structures provide a more economical and technically superior alternative to the traditional techniques in many situations because it offers high strength, low weight, corrosion resistance, high fatigue resistance, easy and rapid installation and minimal change in structural geometry.

II. EXPERIMENTAL PROGRAM

2.1 Specification of specimen:

In this experiment, total 15 no. of beams were casted under 3 different categories i.e. full strength beam, beam weak in shear and beam weak in flexure. In beam weak in shear category of beams, stirrups were provided at grater spacing than full strength beam and in beam weak in flexure category of beams, less tension steel was provided than full strength beam.

This table is showing details of each beam specimens as below:

Specimen	No. of Specimen	Size of beam (mm)	Top Reinforcement	Bottom Reinforcement	Stirrups Detail
Control Beam (CB)	3	200 × 200 × 1000	2 – 10 mm Φ	4 – 10 mm Φ	8 mm Φ @ 95 mm c/c
Weak in Shear (S)	6	200 × 200 × 1000	2 – 10 mm Φ	4 – 10 mm Φ	8 mm Φ @ 155 mm c/c
Weak in Flexure (F)	6	200 × 200 × 1000	2 – 10 mm Φ	2 – 10 mm Φ+ 1 – 8 mm Φ	8 mm Φ @ 95 mm c/c

2.2 GFRP configuration for beams:

To check the effect of strengthening, beams were wrapped by different types of GFRP configurations for all three category of beams.

For full strength beam category, one beam was control beam without GFRP sheet (CB1) where other two beams were wrapped by full side wrapping (S1) and full bottom wrapping (F1), respectively.

For beam weak in shear category, one beam was control beam (CBS1), where other beams were wrapped by full side wrapping (BS2), middle 0.5 depth at sides (BS3), rectangular strips of 50 mm width @ 50 mm spacing at sides (BS4), rectangular 45° inclined sheets of 50 mm width @ 50 mm spacing (BS5) and U-wrapping (BS6), respectively.

For beam weak in flexure category, one beam was control beam (CBF1), where other beams were wrapped by middle 0.5 width of bottom (BF2), full bottom (BF3), middle 0.5 length at bottom (BF4), rectangular strips of 50 mm width @ 50 mm spacing at bottom (BF5) and U-wrapping (BF6), respectively.

2.3 Concrete mix:

Pozzolona Portland Cement was used in preparation of beam specimen. It was tested for physical properties in accordance with Indian Standard specifications. The specific gravity of cement was 3.02. The fine aggregate used in this experiment was clean river sand, passing through 4.75 mm sieve with specific gravity 2.6 and the grading zone of fine aggregate was zone II as per Indian Standard specifications. The maximum size and specific gravity of coarse aggregate was 20 mm and 2.789, respectively. Ordinary clean potable tap water was used for both concrete mixing and curing of concrete.

The concrete mix proportion designed by IS method to achieve the strength of 35 N/mm^2 was **1 : 1.52 : 2.77** by weight. The compressive strength test results were obtained at 7 days and 28 days were 28.63 N/mm^2 and 46.08 N/mm^2, respectively.

2.4 Glass Fiber Reinforced Polymer (GFRP):

Glass Fiber Reinforced Polymers were among the oldest and least expensive of all composite materials. GFRP sheet having fiber oriented in both longitudinal and transverse directions was used. GFRP sheet and epoxy resin both were procured from Sika®India. The epoxy resin was used to attach the GFRP sheet to the beam surface which was mixer of Part A and Part B (2 : 1).

Before bonding the composite fabric onto the concrete surface, the concrete surface was made rough using grinder. Once the surface was prepared to the required standard, the epoxy resin was mixed in accordance with manufacturer's instructions. Mixing was carried out in metal container (Part A: Part B :: 2:1) and was continued until the mixture was in uniform colour. When this was completed and fabric had been cut to the size, the epoxy resin was applied to the concrete surface. The composite fabric then placed on top of epoxy resin coating and the resin was squeezed through the roving of the fabric with plastic laminating roller. This operation was carried out at room temperature.

2.5 Experimental set up:

A single point loading system was adopted for the testing of beams. Beams were tested on Universal Testing Machine (U.T.M.) of 2000 kN capacity. Supports were placed at 100 mm from ends hence effective span of 800 mm. Gradual increasing loading was applied and mid span deflection was measured with help of

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dial gauge. At same time, applied load was measured at every 0.5 mm interval. Testing procedure for all beam was same.

III. RESULTS AND DISCUSSIONS

Total 15 no. of beams were tested for ultimate strength and at same time mid span defection were measured. Beams were tested on Universal Testing Machine (U.T.M.) of 2000kN capacity. Following figures are showing damaged beams after testing:

Fig. 1: Failed beam CB1 after testing

Fig. 2: Failed beam F1 after testing

Fig. 3: Failed beam S1 after testing

Fig. 4: Failed beam CBS1 after testing

Fig. 5: Failed beam BS2 after testing

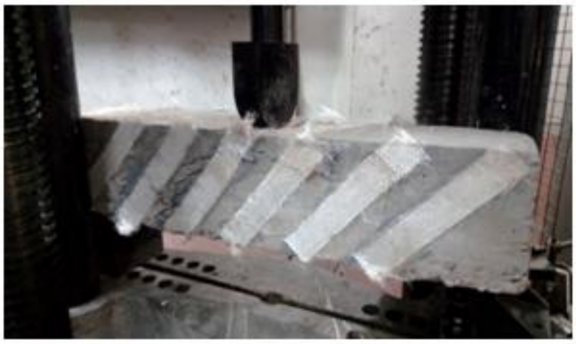

Fig. 6: Failed beam BS3 after testing

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Fig. 7: Failed beam BS4 after testing


Fig. 8: Failed beam BS5 after testing


Fig. 9: Failed beam BS6 after testing


Fig. 10: Failed beam CBF1 after testing


Fig. 11: Failed beam BF2 after testing


Fig. 12: Failed beam BF3 after testing

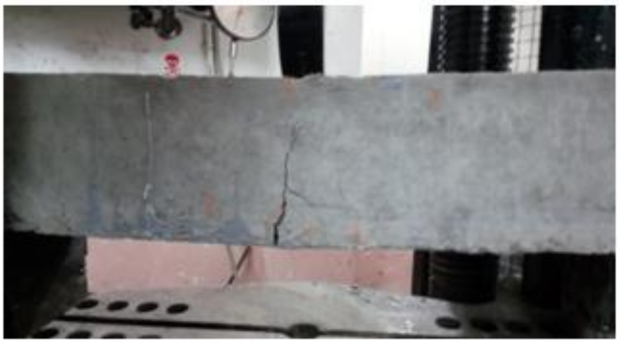
Fig. 13: Failed beam BF4 after testing


Fig. 14: Failed beam BF5 after testing

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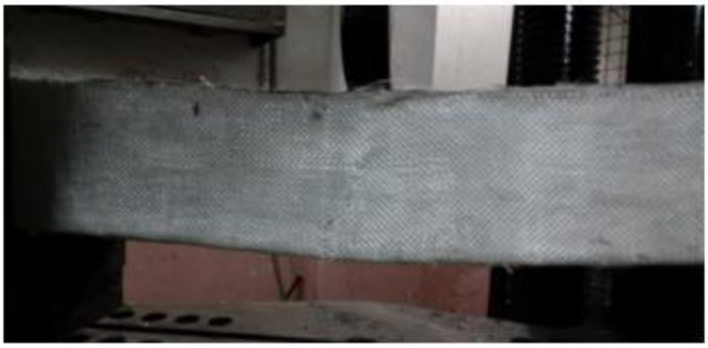

Fig. 15: Failed beam BF6 after testing

3.1 Load vs. Deflection behavior:

Three categories of beams were tested for their ultimate strengths. One beam from each category was taken as control beam where as others were with GFRP sheet with different configuration for each beam. Here the following table and graphs are showing load vs. deflection behavior for all these beams:

		Ultimate Load	Ultimate deflection
Full strength beam	CB1 – Control beam	155.98	9
	S1 – Full side wrap	182.47	6.5
	F1 – Full bottom wrap	201.11	7
Beam weak in flexure	CBF1 – Control beam	124.59	9
	BF2 – Middle 0.5 width at bottom	172.66	6.5
	BF3 – Full bottom wrap	237.4	4
	BF4 – Middle 0.5 length at bottom	186.39	7
	BF5 – horizontal strips at bottom	206.01	5
	BF6 – U-wrap	245.25	4
Beam weak in shear	CBS1 – Control beam	134.4	8.5
	BS2 – Full side wrap	271.74	6
	BS3 – Middle 0.5 depth at sides	252.12	4.5
	BS4 – vertical strips at sides	219.74	6.5
	BS5 – Inclined strips at sides	237.4	5
	BS6 – U-wrap	266.83	4

Table 1: Results for all tested beams

Fig. 16: Load Vs. Deflection curve of Full strength beams

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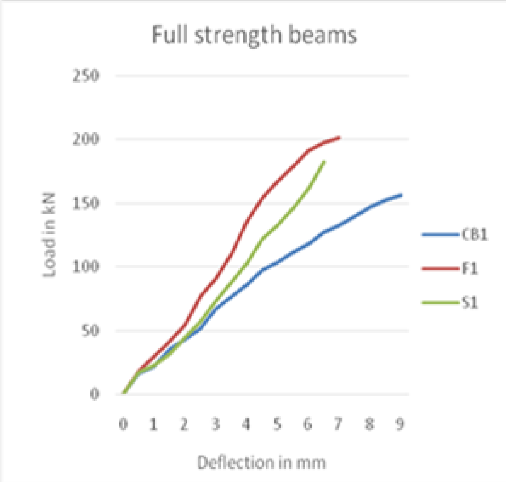


Fig. 17: Load Vs. Deflection curve of Beams weak in flexure

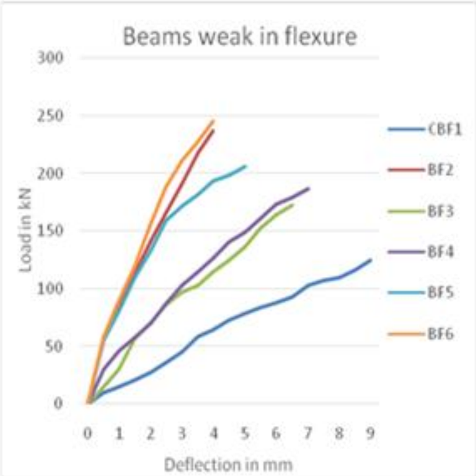
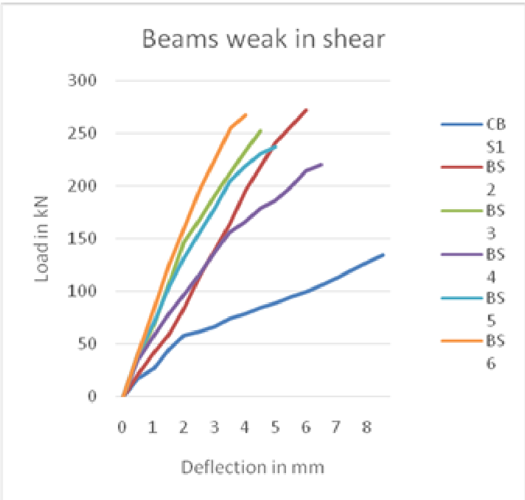


Fig. 18: Load Vs. Deflection curve of Beams weak in shear



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Load vs. Deflection curve of the beams are shown in graphs. From the above graphs, it is quite clear that beams having U-wrapping have better load vs. deflection behavior in all these beams. There is good improvement in all strengthened beams than their respective control beams.

3.2 Comparison of ultimate load of beams:

The following graph is showing ultimate load for all these beams for all three category as shown below:

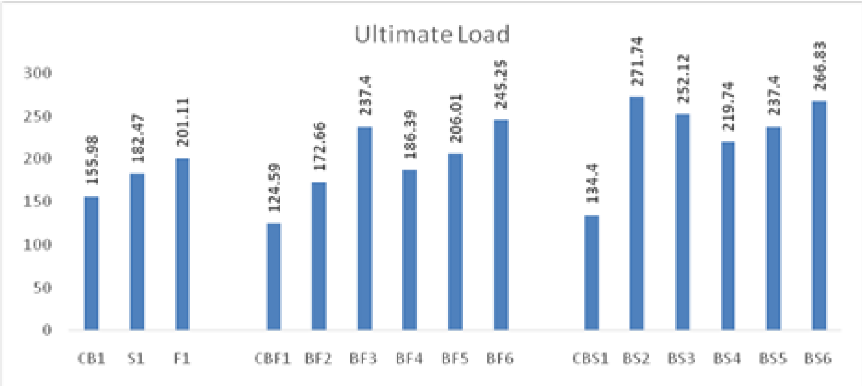

Fig. 19: Comparison of ultimate load for all beams

From graph, it can be easily understand that the strengthened beam have better ultimate load capacity. In case of full strength category of beams, beam strengthened with bottom wrap (F1) shows good increment in their ultimate load as 28.23% compared to their control beam. For beam weak in shear category beams, beam strengthen with Full side wrap (BS2), U-wrap (BS6) and Middle 0.5 depth at sides (BS3) shows 102.19%, 98.53% and 87.59% increment in their ultimate load compared to control beam. For beam weak in flexure category, beam strengthened with U-wrap (BF6) and full bottom wrap at bottom (BF3) shows 96.85% and 90.54% increment in ultimate load compared to control beam.

3.3 Comparison for ultimate deflection of beams:

The following graph is showing ultimate deflection for all these beams for all three category as shown below:

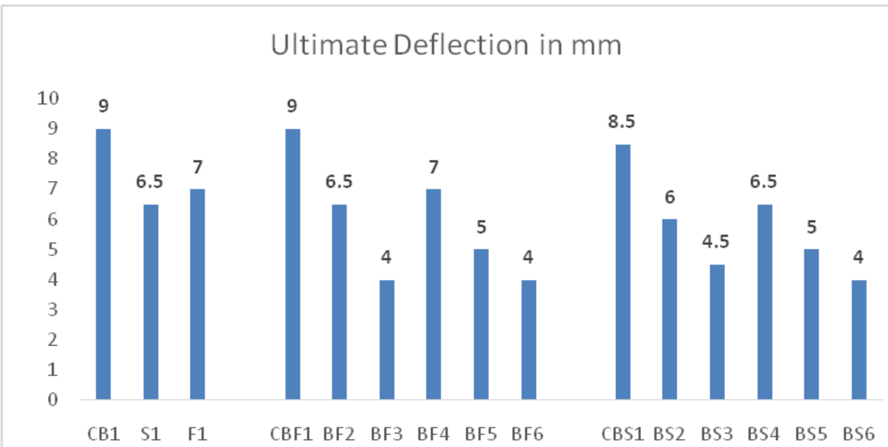

Fig. 20: Comparison of ultimate deflection for all beams

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From graph and table, it can be easily understand that the strengthened beam have better decrement in ultimate deflection. In case of full strength category of beams, beam strengthened with side wrap (S1) shows good decrement in their ultimate deflection as 27.78% compared to their control beam. For beam weak in shear category beams, beam strengthen with U-wrap (BS6), Middle 0.5 depth at sides (BS3) and inclined strips (BS5) shows 52.94%, 47.06% and 41.18% decrement in their ultimate deflection compared to control beam. For beam weak in flexure category, beam strengthened with U-wrap (BF6) and middle 0.5 width at bottom (BF3) and horizontal strips (BF5) shows 55.56%, 55.56% and 44.44% decrement in ultimate deflection compared to control beam.

3.4 Comparison for Stiffness of beams:

Beam stiffness is the factor which generally shows how much load the beam can carry. Here, stiffness is calculated by dividing ultimate load to ultimate deflection. Following graph is showing the stiffness of beams shown below:

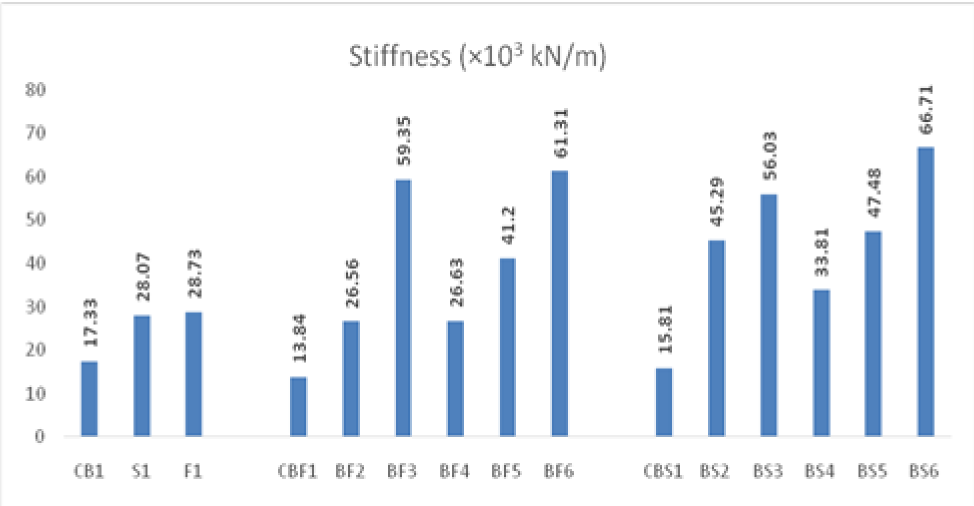

Fig. 21: Comparison of stiffness for all beams

From table, it is quite understood that in full strength beam, stiffness is increased upto 65% than control beam. In case of beam weak in shear, stiffness is increased 321% (3.2 times than control beam's stiffness) & 255%(2.5 times than control beam's stiffness) for middle 0.5 middle depth at sides (BS3) and U-wrap (BS6) respectively and in case of beam weak in flexure, stiffness is increased 343% (3.4 times than control beam's stiffness) and 329% (around 3.3 times than control beam's stiffness) for U-wrap (BF6) and Full bottom wrap (BF3) respectively.

3.5 Comparison for Energy absorption of beams:

Here, Energy absorption is found out by calculating area under load vs. deflection curve. In procedure for finding out of area under load deflection curve, Firstly mid ordinate for each reading is found out by averaging

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two readings and then these mid ordinates are multiplied by deflection interval i.e. 0.5mm. After that, sum of all these multiplication gives the final area covered under load deflection curve.

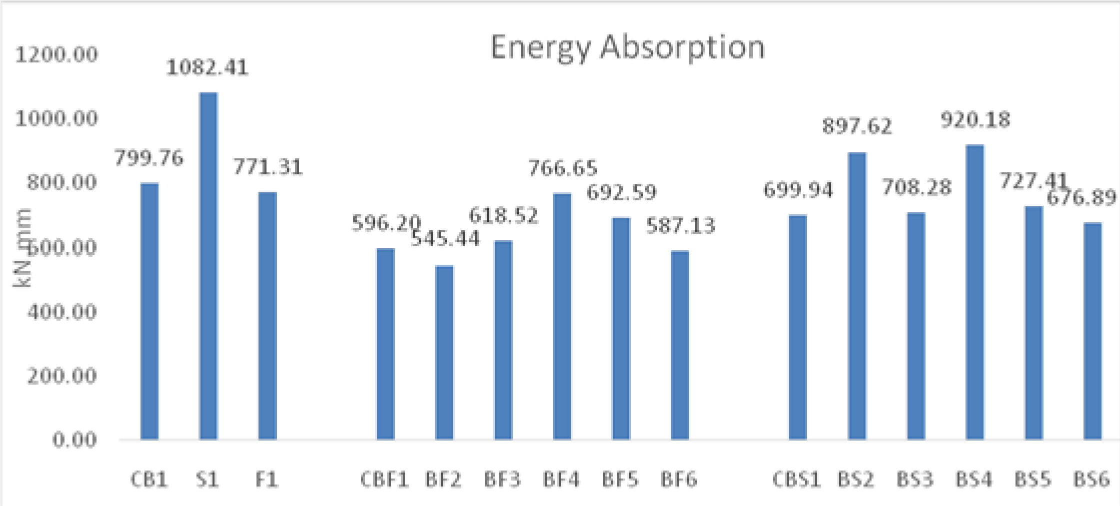

Fig. 22: Comparison of energy absorption for all beams

The graph is showing the increment in energy absorption capacity of the beam where as in some cases this value is decreased i.e. for BF2, BF6, BS6. Energy absorption is increased up to 28.58% for beam weak in flexure. For beam weak in shear, this increment is up to 31.46%.

5. Conclusions

In this experiment, total 15 no. of beams were tested in 3 different categories i.e. Full strength beam, Beam weak in shear and beam weak in flexure for single point loading. Here the following conclusions are drawn:

1. Full strength beam:

- Ultimate load of full strength beam category beams enhanced between 16.98% to 28.93% w.r.t. control beam, still deflection reduced between 22.22% to 27.78%.
- Stiffness of full strength beam category beams enhanced between 61.97% to 65.78%.
- First crack load of full strength beam category beams enhanced up to 150%.

2. Beam weak in shear:

- Ultimate load of beam weak in shear category beams enhanced between 63.50% to 102.19% w.r.t. control beam, still deflection reduced between 23.53% to 52.94%.
- Stiffness of beam weak in shear category beams enhanced between 113.85% to 321.95%.
- First crack load of beam weak in shear category beams enhanced up to 383%.
- Energy absorption capacity of Beam weak in shear capacity enhanced up to 31.48%.

3. Beam weak in flexure:

- Ultimate load of beam weak in flexure category beams enhanced between 38.58% to 96.85% w.r.t. control beam, still deflection reduced between 22.22% to 55.56%.

- Stiffness of beam weak in flexure category beams enhanced between 91.91% to 341.99%.
- First crack load of beam weak in flexure category beams enhanced up to 503%.
- Energy absorption capacity of beam weak in flexure category enhanced up to 28.58%.

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